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SUBMISSILE AERODYNAMICS DURING DISPENSING

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14 May 81

ABSTRACT

A combined analytical and experimental study was conducted to determine the aerodynamic interference effects of a submissile in the presence of a dispenser missile. The analytical predictions are made using NEAR codes modified for applications to missile systems. A wind tunnel test was conducted to measure the static aerodynamic coefficients of a submissile in the flow field of a dispenser missile at Mach numbers 0.8 and 1.2. The parameters observed to have the greatest effect on the interference aerodynamics are the addition of fins on the submissile, the removal of the dispenser bay covers, the dispenser angle of attack and the submissile pitch angle.

INTRODUCTION

Several missile systems are currently being developed involving the release of submissiles from a dispenser missile. The deployment of submissiles may occur over a range of Mach numbers from 0.5 to 2.0 and over a range of angles of attack from 0 to 30 deg. The initial motion of the submissile is dominated by aerodynamic interference forces which influence the trajectory that follows. The aerodynamic interference forces must be known to determine the transient loads during deployment that are critical to target lock-on. The results of a survey by Lockheed for the U.S. Army Missile Command (MICOM) showed that there are very little experimental data available for evaluating interference. Several aircraft store separation codes were identified which with modifications, can be used for multiple missiles. However, the accuracy of the codes is unknown.

In an effort to gain an understanding of the aerodynamic interference, MICOM sponsored a combined analytical and experimental study to determine the aerodynamic interference effects of a submissile in the presence of a dispenser missile. The analytical effort was directed toward identification of the applicable computer codes and the modification of selected codes for application to the missile-submissile systems. The modified Nielson Engineering and Research (NEAR) subsonic and supersonic aircraft-store separation codes were used to generate aerodynamic interference data on the submissile for various locations relative to the dispenser missile. Simultaneously, a wind tunnel test was conducted to measure the static aerodynamic coefficients of a submissile in the flow field of a dispenser missile.

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Several parameters were varied to determine their effect on the interference aerodynamics of the submissile. Some test runs were specifically made for a direct comparison with the NEAR code results.

The purpose of this paper is to present the results of the wind tunnel test data analysis, and a comparison of some of the results with the NEAR code predictions. The wind tunnel results are presented for the interference forces and moments on a submissile in the presence of a dispenser with and without bay covers. The NEAR codes do not have any provision for simulating a dispenser without bay covers and thus the predicted results are for the dispenser with bays closed. For the sake of brevity the results are presented for parameters which most affect interference aerodynamics. The results for parameters not presented are available upon request.

In general, the interference effects are observed to be the largest for submissile locations closest to the dispenser. A submissile located very close to a dispenser with bays open is characterized by large negative normal force coefficients and large positive pitching moment coefficients. The parameters which affect the interference aerodynamics the most are, the addition of fins on the submissile, the removal of the dispenser bay covers, the dispenser angle of attack and the submissile pitch angle. Whereas, the fin orientation, the nose shape and the submissile yaw angle did not influence the interference aerodynamics greatly. Comparison of the wind tunnel test data and the NEAR code predictions does not show good agreement.

WIND TUNNEL TEST DESCRIPTION

The wind tunnel test was conducted in the Vought Corporation High Speed Wind tunnel. The test models were designed and fabricated by the Jet Propulsion Laboratory. The dispenser model was designed to resemble a typical Army missile. This model has three sets of bays in its forward section for storage of submissiles. Because of its position on the constricted area of the three caliber ogive nose, the forward set of bays has positions for only five submissiles of the size desired. The center and aft bay positions can each accommodate eight.

Sketches of the preliminary design indicated that a rather long sting was needed to support the submissile. Use of such a sting would have restricted the angle of attack obtainable and vertical displacement as well as inducing possible deflection problems. To shorten the sting, it was necessary to truncate the dispenser model and move it aft on its sting. The result was that the center of pressure of the truncated model was too far forward of the balance center for any available balance to withstand the loads. Although it was desired to measure the interference effects of the submissile on the dispenser missile, the decision was made to replace the dispenser balance with a solid sting.

The model tested was a 5.593 in. long, 0.932 in. diameter axisymmetrical vehicle designed to represent typical submissile type configurations and investigate certain configuration parameters. The model could be configured

with a tangent ogive nose of either 1/2 or 2 calibers. It could be tested either with or without its four aft mounted rectangular fins. The submissile model was designed to be tested in the presence of the forebody model of a dispenser missile. The dispenser had a 3.750 in. diameter cylindrical body, a 3 caliber ogive nose and three sets of submissile bays, in the nose and forward part of the body, each with several submissile storage positions. There was also a second submissile model which was the same configuration as the model to be tested, but non-metric and designed to mount to the dispenser missile using a pylon. This non-metric submissile was used to determine the effect of its wake on the metric submissile which was tested behind it. The submissile and dispenser dimensions are shown in Figures 1 and 2.

The metric submissile was designed to fit on a six-component internal balance to be able to obtain total vehicle static stability coefficients and base pressure coefficients. The Vought Flight Dynamics Simulator was used to obtain these coefficients while in the presence of the dispenser vehicle. With the non-metric submissile mounted to the dispenser missile, the metric submissile was used to obtain coefficients while in the presence of the dispenser missile and in the wake of a more forward submissile.

The models were tested in several configurations and over a range of several parameters described in the table below.

Test Parameter Ranges

α_D	Dispenser angle of attack	-5 to +5 deg
$\Delta\alpha_S$	Submissile angle of attack relative to dispenser	-10 to +10 deg
M	Mach number	0.4 to 1.4
X	Horizontal distance behind nose of dispenser to submissile center of gravity, positive for submissile moving aft of dispenser nose	1 to 5 diameters (dispenser)
Z	Vertical distance of submissile from dispenser, positive for submissile moving down (below) dispenser	1/2 to 3 diameters

DESCRIPTION OF ANALYTICAL CODES

The NEAR subsonic and supersonic computer codes were developed by Nielson Engineering and Research to predict the trajectories of external stores dropped from an aircraft. Some modifications to the NEAR codes

were necessary for application to missile systems. The first attempt to calculate aerodynamic forces on a submissile in the flow field of a carrier missile, using the NEAR codes, was made by reducing the wing size, modeling the dispenser missile as the fuselage and the submissile as the store. In the subsonic case the reduced wing was placed far behind the fuselage. In the supersonic case the reduced wing was placed at the tail end of the fuselage. The program would not run if the wing was placed farther aft.

In order to further improve the efficiency of the codes, modifications were made to the codes to eliminate completely the input and calculations related to the dispenser missile wing. Basically, the store data were converted to fuselage coordinate system, which in the original program were given relative to the wing. Also, the flowfield computations were allowed to bypass the subroutines involving the wing influence. The modified NEAR codes were exercised for the Army models tested in the wind tunnel. It was observed that the submissile aerodynamics obtained using the two techniques: (1) reduction of the wing to a small size and its placement far away from the fuselage, and (2) elimination of the wing, were identical. A substantial reduction in the execution time was, however, achieved by eliminating the wing. Comparable execution times for six selected lateral positions for the subsonic case using the two techniques were 14.21 and 0.583 sec, respectively. The execution time for seven consecutive cases for the supersonic case was 1.099 sec compared to 6.46 sec for the reduced wing case.

An option was added to the NEAR code to facilitate the generation of parametric data base. The original version moved the store along a trajectory determined by the forces experienced. The option allows the submissile to follow a predetermined path for which the aerodynamics can be calculated. The option currently allows a single parameter to be varied in even increments. Either position (X, Y, Z) or attitude (θ, ψ, ϕ) can be varied, the increment and the maximum value of the parameter.

The results were obtained in terms of the incremental normal force and pitching moment coefficients. The parameters varied were the geometric placement of the submissile relative to the dispenser missile (X location, Z location, and relative attitude), and the freestream Mach number.

DESCRIPTION OF RESULTS

The results are presented in terms of the interference pitch plane coefficients plotted as a function of submissile geometric location relative to the dispenser missile. These results are presented for two Mach numbers. The effect of the parameters varied on the submissile interference aerodynamics will be discussed in the following paragraphs.

RADIAL SEPARATION

Typical results for a submissile traversing a vertical trajectory are shown in Figure 3 for a submissile deployed from a dispenser with bays closed and open. The closed bay results for Mach number = 0.8 do not

show appreciable interference effects in the values of the normal force, the pitching moment, and the axial force coefficients. However, the removal of bay covers significantly alters the submissile aerodynamics. The interference effects with bays open are largest for a submissile location closest to the dispenser. Typical largest values of the normal force and the pitching moment coefficient are -0.65 and 1.4, respectively. The axial force coefficient has a minimum value of 0.09 at this location. The interference aerodynamic coefficients are observed to approach their freestream values at about three diameters below the dispenser. The supersonic results with bays open are similar to the subsonic case showing a large negative normal force coefficient and a large positive pitching moment coefficient when closest to the dispenser. The submissile axial force coefficient increased from 0.2 when closest to the dispenser to about 0.4 at three diameters below the dispenser. It is noted that the data were a function of the submissile location in the wind tunnel and affects the interference plots at larger separation distances.

LONGITUDINAL SEPARATION

The results of the longitudinal sweep of a submissile for three vertical locations below the dispenser are presented in Figure 4. The interference effects are observed to be largest at submissile locations under the nose portion of the dispenser. Mach = 0.8 results show no appreciable variation in the interference values after the submissile has traversed about three diameters behind the dispenser nose. The results at a supersonic Mach number of 1.2 show that both the normal force and the pitching moment drop down to zero at about five diameters behind the dispenser nose.

FIN ORIENTATION

The addition of fins have a significant effect on the interference aerodynamics of a submissile. However, the fin orientation does not influence the magnitude of the interference effect greatly. Figure 5 shows the aerodynamics data for a finless submissile and submissiles with three fin orientations. The results have been plotted for submissiles traversing a vertical trajectory from the center bay of the dispenser. Compared with finless submissiles the finned submissiles have a larger negative normal force and a larger positive pitching moment when closest to the dispenser. The finned submissiles have larger axial force compared to the finless submissile, however, the interference increment is similar for the two cases.

WAKE EFFECT

A submissile deployed from a dispenser in the wake of another submissile is in the interference flow field of both the dispenser and the submissile. Plots in Figure 6 depict the aerodynamic coefficient variation of a submissile traversing a vertical trajectory starting from the center bay of the dispenser. The front submissile is located at two diameters below a longitudinal location simulating a forward bay of the dispenser. The pitch plane aerodynamic coefficients are observed to oscillate about their nominal values as the submissile traverses through the wake of the forward submissile.

DISPENSER ANGLE OF ATTACK

The dispenser angle of attack greatly influences the aerodynamics of the dispensing submissile. Typical results for a submissile deployed from a forward bay of the dispenser at 0 and ± 5 deg angle of attack are shown in Figure 7. Note that the submissile angle of attack relative to the freestream is the same as the dispenser in each case. At a subsonic Mach number of 0.8 the interference effects are found to be greatest for a dispenser angle of attack of 5 deg. An estimate of the magnitudes of the maximum incremental normal force and pitching moment coefficients are -1.0 and 1.0, respectively. There is no significant effect, however, on the value of the submissile normal force coefficient for the case of dispenser at -5 deg angle of attack. The axial force coefficients did not vary much from their interference free values except when closest to the dispenser. Similar general trends are obtained for a supersonic Mach number of 1.2 with the exception of axial force reduction close to the dispenser. The value of this interference did not vary with dispenser angle of attack.

SUBMISSILE PITCH

Positive submissile pitch produces positive normal forces and negative pitching moments. Typical results for a submissile at 0 and ± 10 deg pitch angle (and dispenser at zero) are presented in Figure 8. Both at $M = 0.8$ and at $M = 1.2$, the interference effects are largest at zero degree pitch angle. At $M = 0.8$ the interference normal force coefficients and the pitching moment do not vary appreciably from their freestream values. For the supersonic Mach number of 1.2, the interference effects are observed up to about two diameters below the dispenser.

COMPARISON OF WIND TUNNEL RESULTS AND NEAR CODE PREDICTIONS

The submissile aerodynamic interference data obtained in the wind tunnel have been compared to the analytical predictions developed with the NEAR codes. The subsonic results at a Mach number of 0.8 for a submissile without fins are presented in Figures 9 and 10. Figure 9 shows the effect of lateral separation of a submissile from the dispenser placed parallel to the free stream. The normal force coefficient obtained in the wind tunnel is of opposite sign compared to the NEAR code predictions. The wind tunnel normal force data for this configuration is not typical of the general trends which show negative normal force for a submissile closest to the dispenser. The pitching moment data, however, are in reasonable agreement. The effect of dispenser angle of attack is also shown in Figure 9. The predicted normal force is significantly different from the measured data for submissile locations up to one diameter below the dispenser. The pitching moment magnitude, however, is in disagreement even at larger distances from the dispenser. The persistent interference beyond three diameters in the experimental data shown in Figure 9 is possibly due to the wind tunnel flow angularity. The variation of the interference normal force and the pitching moment coefficient for the submissile at an angle of attack with respect to the dispenser is shown in Figure 10. The results are for a submissile located one diameter below the dispenser.

The interference effects of a submissile for a supersonic Mach number of 1.2 are presented in Figures 11 through 16. Reasonable agreement observed for a submissile without fins at a longitudinal location simulating a forward bay, traversing laterally apart in a fixed trajectory. These results are shown in Figure 11. However, at a different longitudinal location simulating a center bay, comparison is not good as shown in Figure 12. The effect of the dispenser angle of attack on the submissile aerodynamics is shown in Figure 13. Both the predicted and the experimental results follow similar trends. The effect of submissile fins in the dispenser interference flow field has not been predicted accurately. This is observed in Figure 14 which depicts longitudinal sweeps of a submissile with fins at a fixed lateral location. Incremental normal force and pitching moment variation with angle of attack agree reasonably well with experimental data (see Figure 15).

The modified NEAR codes are used to determine the submissile interference aerodynamics in the presence of regular shaped dispenser geometries. They cannot, in their present form, determine the flow field around a dispenser with its bays open. This is one of the biggest limitations on the use of the NEAR codes for practical situations of submissile being deployed from a dispenser with bays open. Therefore, the experimental data for the dispenser with open bays can be compared with only the results of the dispenser with closed bays predicted by the NEAR codes. Typical results are shown in Figure 16 for a submissile traversing a longitudinal trajectory at a fixed vertical location. Note that the comparison shown is for different nose shapes, but the effect of the nose shape on the interference normal force and the pitching moment coefficients is insignificant as observed in the submissile aerodynamics wind tunnel test data analysis. The disagreement between the wind tunnel data and the NEAR code prediction is primarily because the NEAR codes cannot determine the flow field around an open bay dispenser.

CONCLUSIONS

The following conclusions are drawn from an analysis of the wind tunnel test conducted to determine the aerodynamic interference effects of a submissile in the flow field of a dispenser:

In general, the interference effects are observed to be largest when the submissile is located closest to the dispenser. This is characterized by large negative normal force coefficients and large positive pitching moment coefficients. The axial force coefficient however decreases to its lowest value for these locations. The interference effects are reduced considerably by covering the dispenser bays. This reduction is pronounced at $M = 0.8$ for which the normal force and pitching moment coefficients do not differ appreciably from their freestream values.

In a longitudinal sweep, the submissile experiences considerable aerodynamic interference when it is under the nose portion of the dispenser. For a Mach number of 1.2 the interference effects reduce to zero at approximately seven diameters behind the nose of the dispenser.

The finned submissile experiences greater interference effects compared to a finless submissile. However, interference aerodynamics of the finned submissile is observed to be independent of the fin orientation.

The aerodynamics of a submissile is altered when deployed in the presence of another submissile. The effect is more pronounced as a submissile traverses through the wake of the forward missile.

The submissile interference aerodynamics are at positive dispenser angles of attack and are larger than zero or negative dispenser angle of attack.

The submissile attitude relative to the dispenser affects the submissile aerodynamics considerably. For positive pitch angles the submissile develops a positive normal force and a negative pitching moment, and vice versa for negative submissile pitch angles. Interference effects are more pronounced at zero attitude when the submissile is parallel to the dispenser missile.

A complete evaluation of the NEAR codes has not been made at the present time. However, some general conclusions are drawn based on the limited comparisons. The disagreements in the NEAR code prediction and experimental results are observed both in the subsonic and the supersonic cases. In the subsonic flow, the difference is due to the underprediction of bouyancy contribution to the normal force in the NEAR code. In the supersonic case, however, no definite reason can be given regarding the difference in agreements of interference forces at two longitudinal locations under the dispenser. No comparison is made of trajectories for which the submissile traversed through the shock wave off the dispenser nose.

For a case of submissile with fins, it was observed that the approach taken in the NEAR codes does not simulate the fin contribution correctly. Finally, the NEAR codes in their present form cannot simulate a dispenser missile with open bays and, therefore, the resulting submissile interference aerodynamics cannot be predicted.

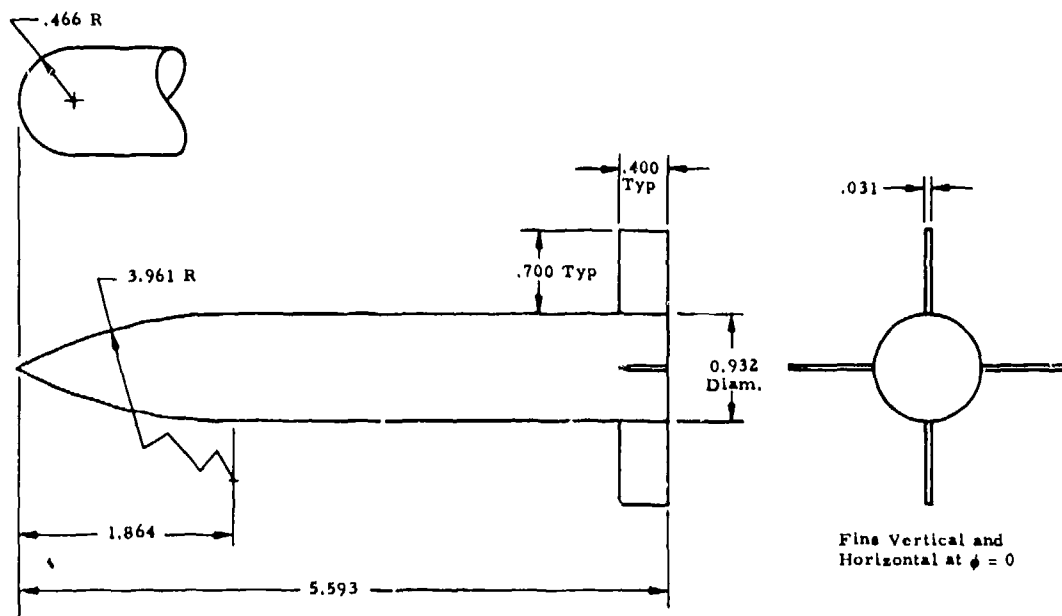


Figure 1. Submissile Design

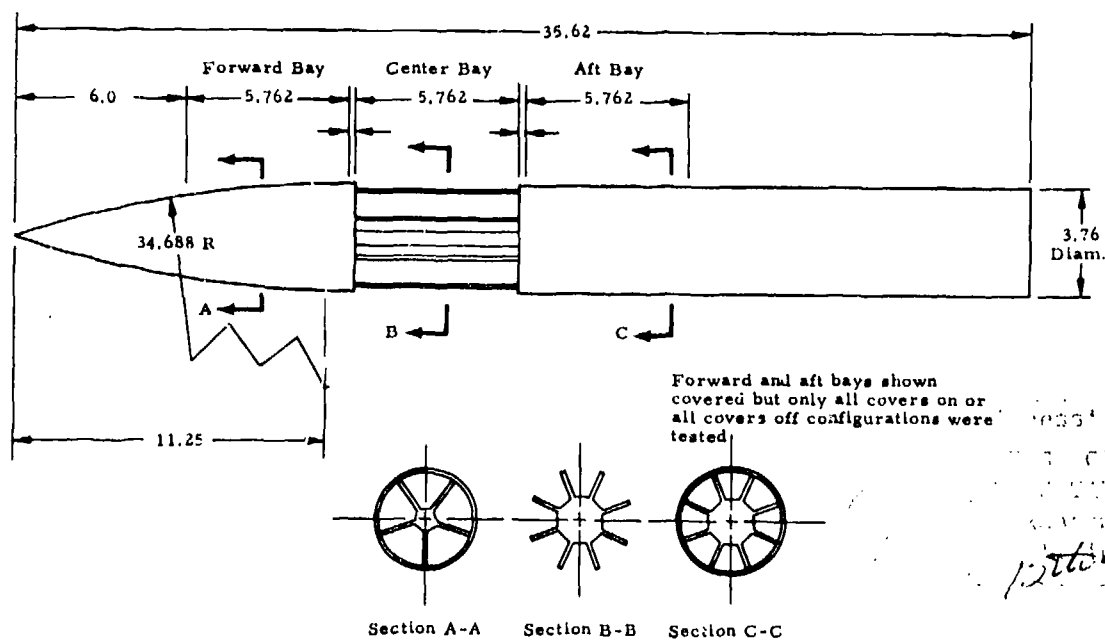


Figure 2. Dispenser Missile Design

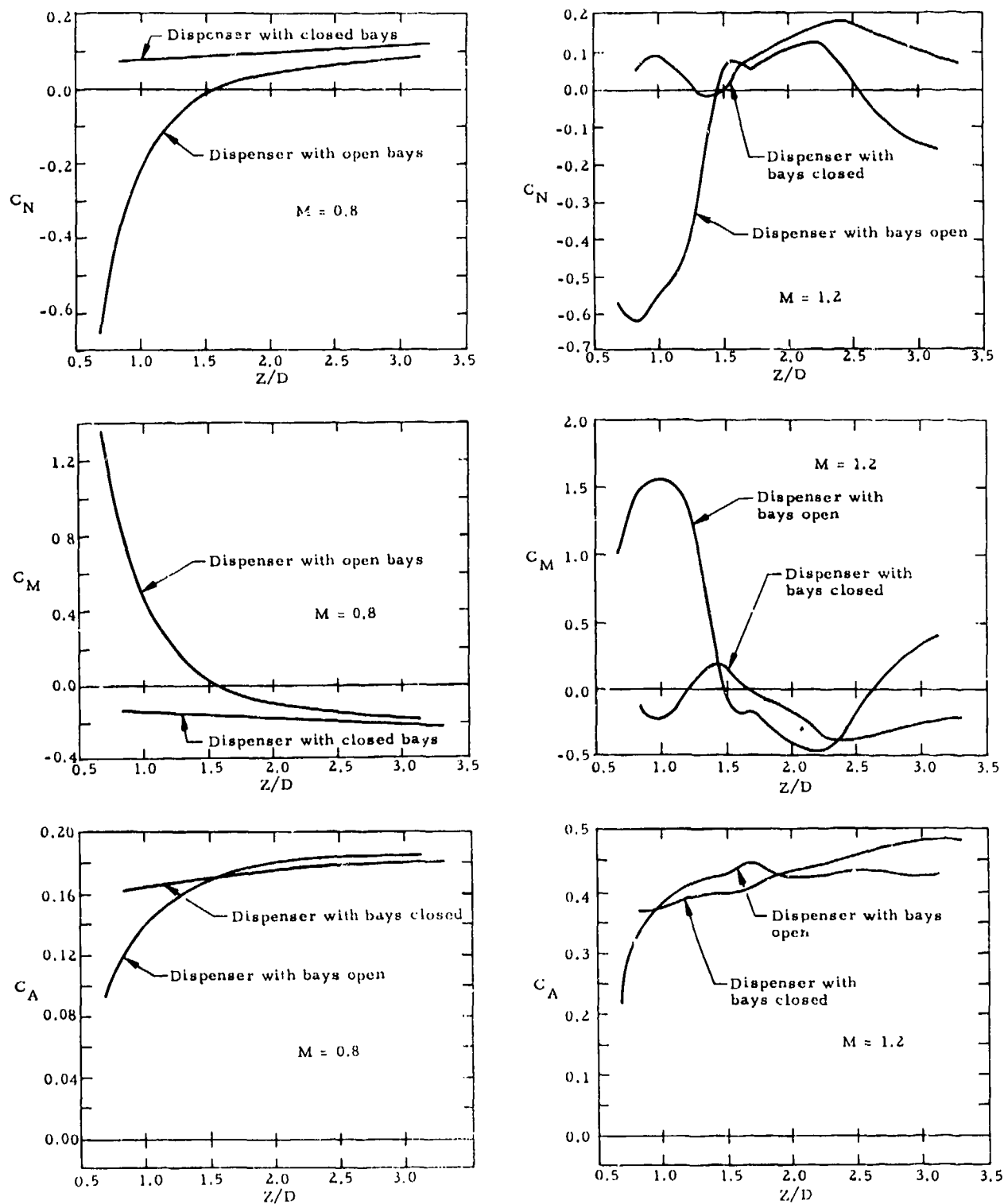


Figure 3. Submissile Aerodynamics as a Function of Submissile Vertical Position ($X/D = 4.0$, $\alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg)

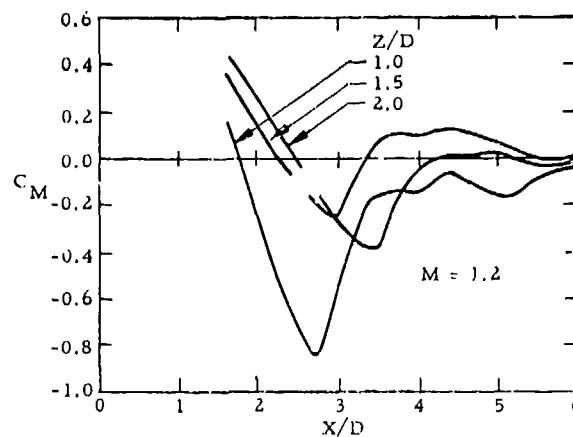
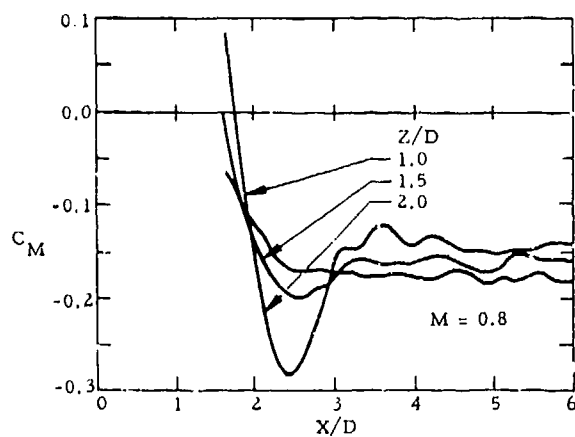
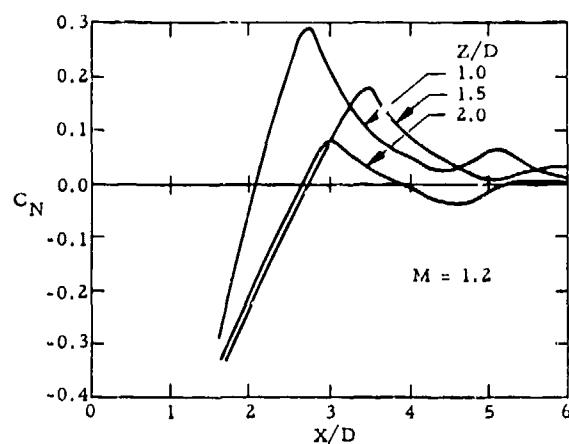
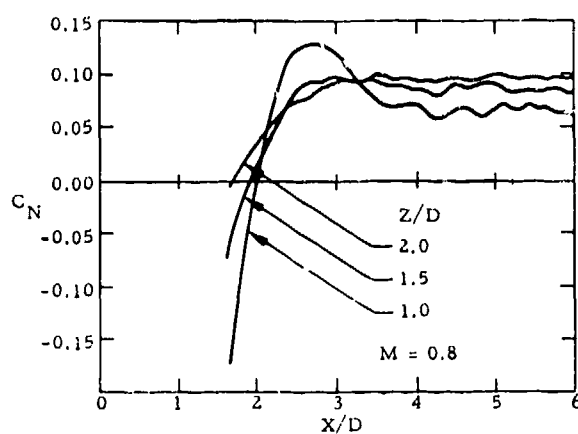


Figure 4. Submissile Aerodynamics as a Function of Submissile Longitudinal Position ($\alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg)

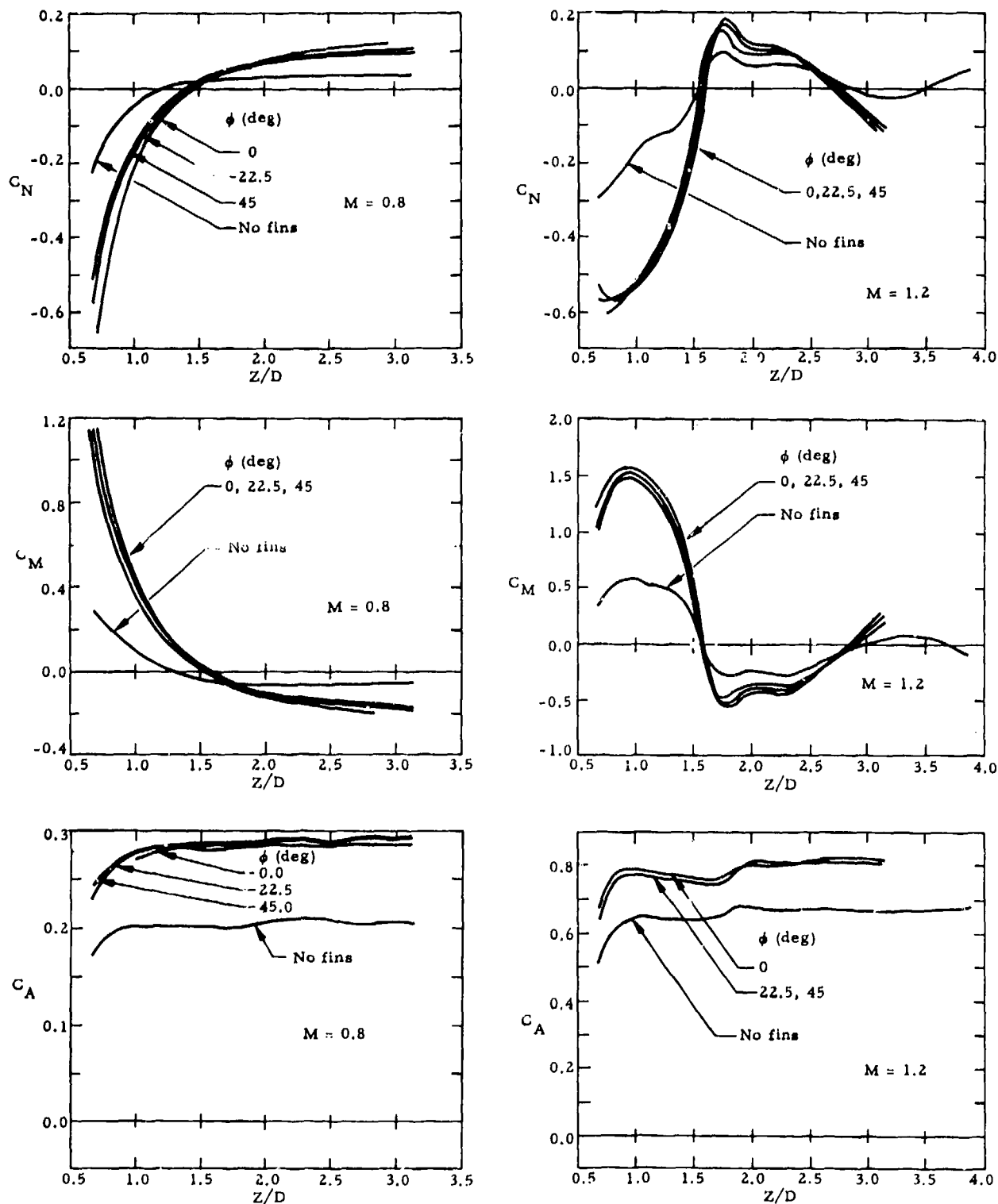


Figure 5. Effect of Fin Orientation on Submissile Aerodynamics
($X/D = 4.0$, $\alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg)

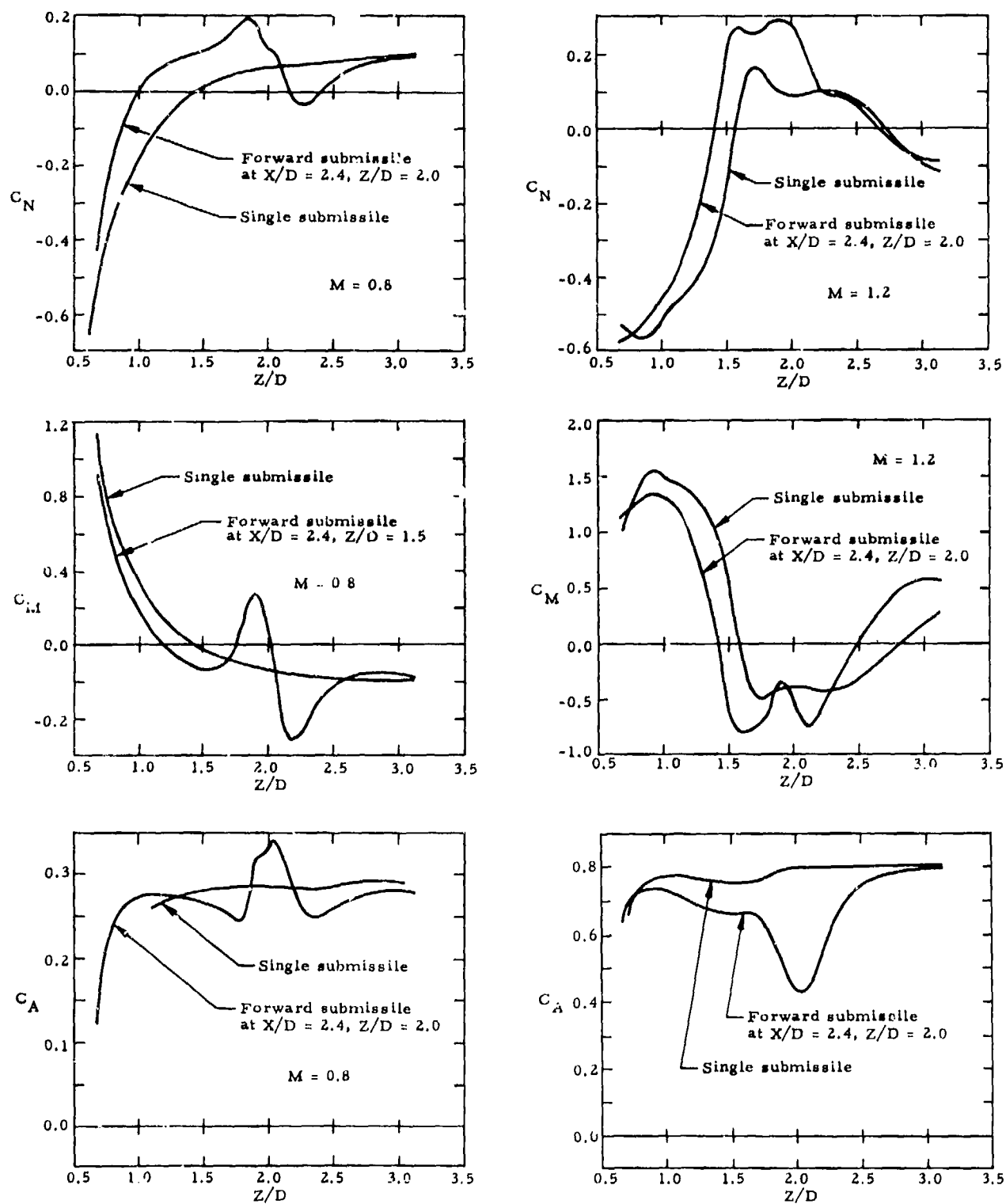


Figure 6. Submissile Interference Aerodynamics in the Wake of Another Submissile ($X/D = 4.0, \alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg)

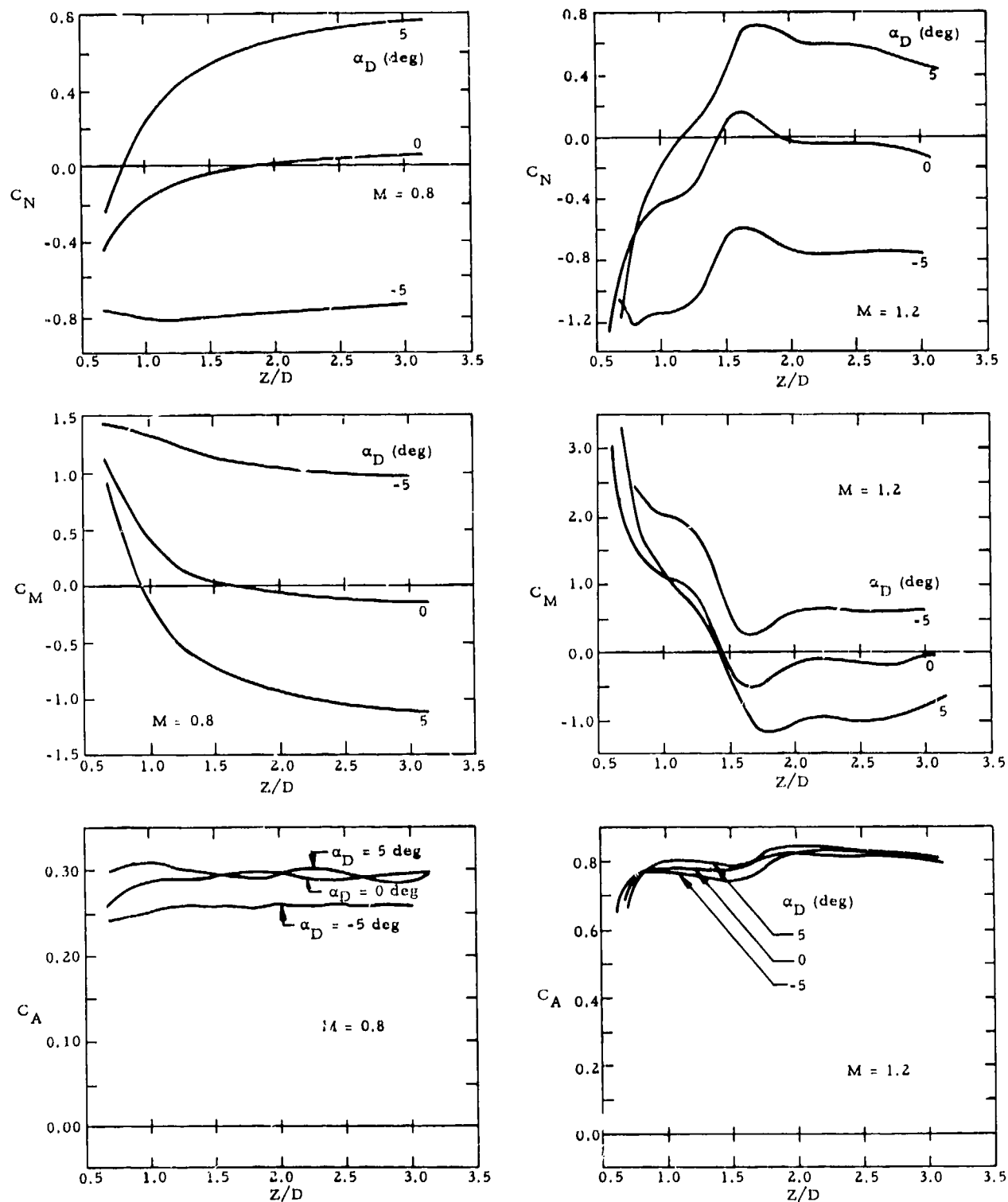


Figure 7. Effect of Dispenser Angle of Attack on Submissile Aerodynamics ($X/D = 2.4$, $\alpha_D = 0^\circ$, $\Delta\alpha_S = 0^\circ$)

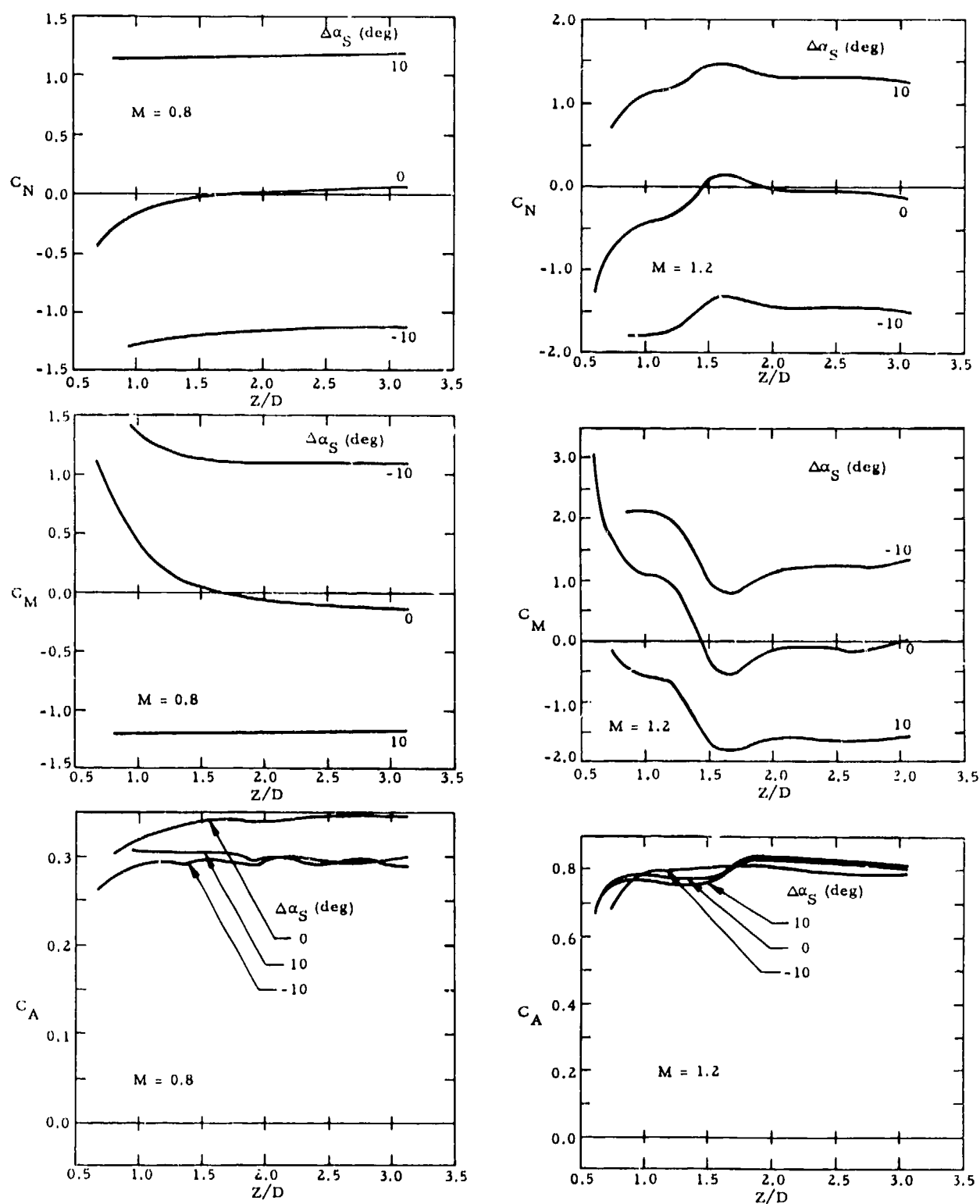


Figure 8. Effect of Submissile Pitch on Submissile Aerodynamics ($X/D = 4.0$, $\alpha_D = 0$ deg)

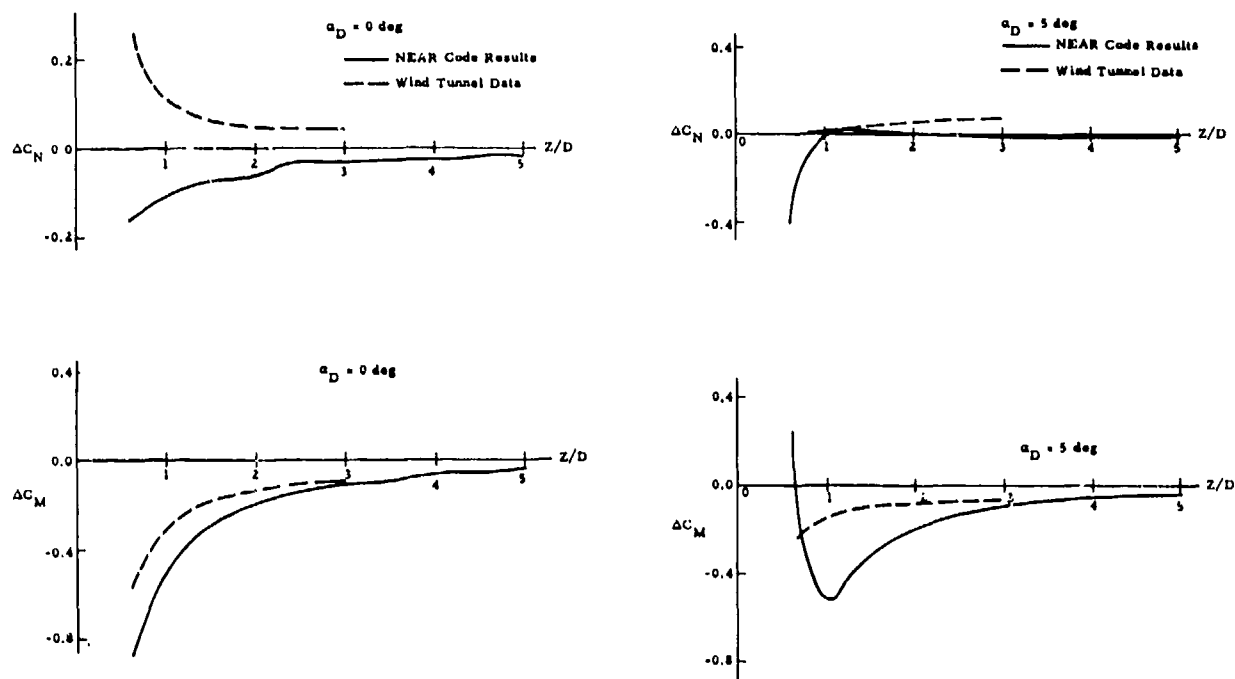


Figure 9. Comparison of Submissile Interference Aerodynamics as a Function of Submissile Vertical Displacement ($M = 0.8$, $\Delta\alpha_S = 0 \text{ deg}$)

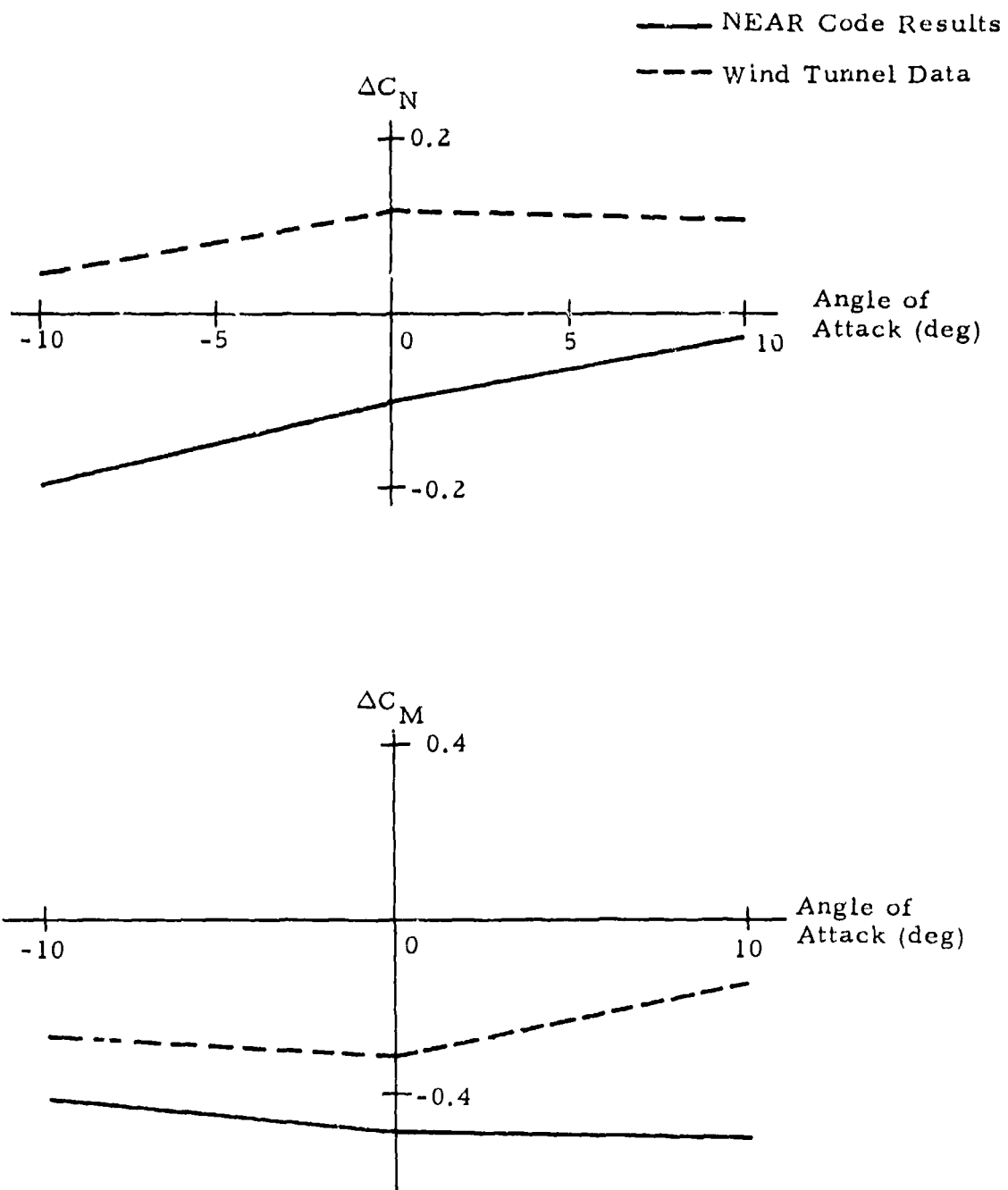


Figure 10. Comparison of Submissile Interference Aerodynamics as a Function of Submissile Angle of Attack Relative to Dispenser ($M = 0.8$, $X/D = 2.4$, $Z/D = 1.0$, $\alpha_D = 0$ deg)

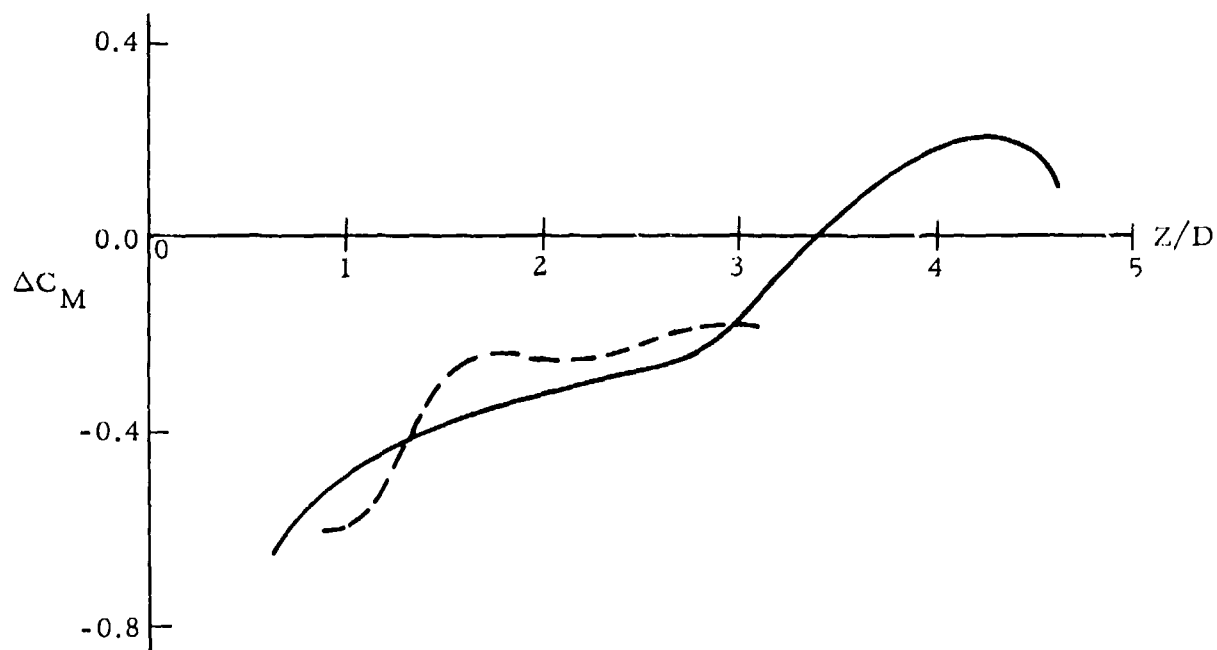
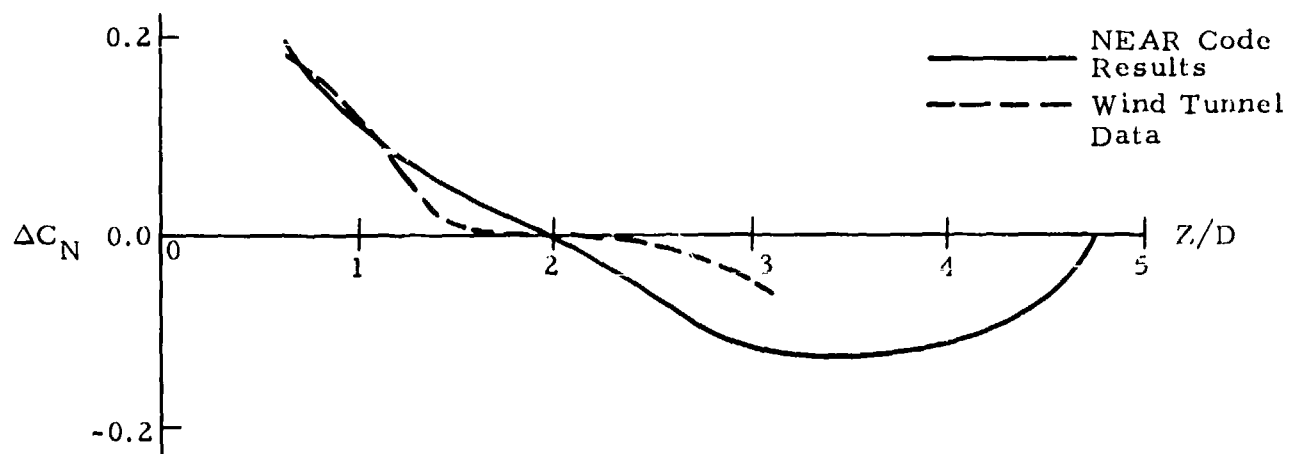


Figure 11. Comparison of Submissile Interference Aerodynamics as a Function of Submissile Vertical Displacement ($M = 1.2$, $X/D = 2.4$, $\alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg)

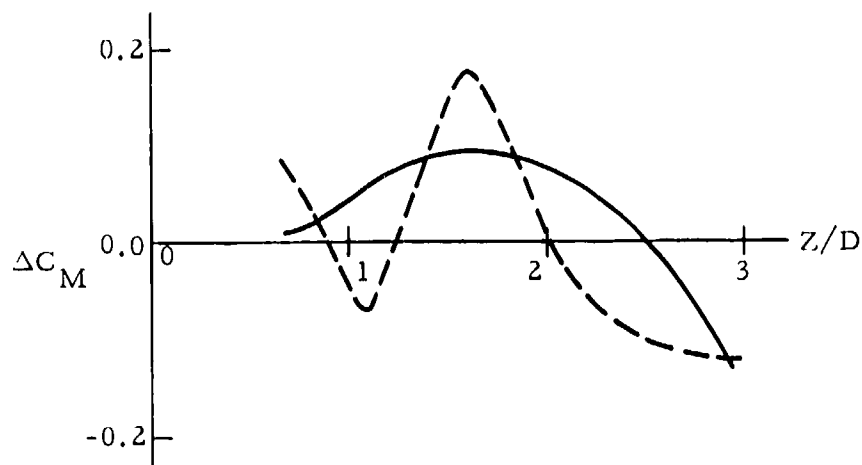
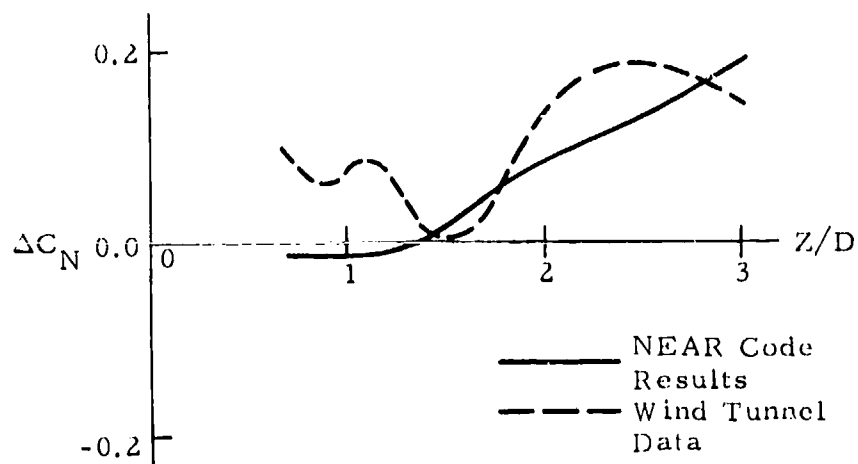


Figure 12. Comparison of Submissile Interference Aerodynamics as a Function of Submissile Vertical Displacement ($M = 1.2$, $X/D = 4.0$, $\alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg)

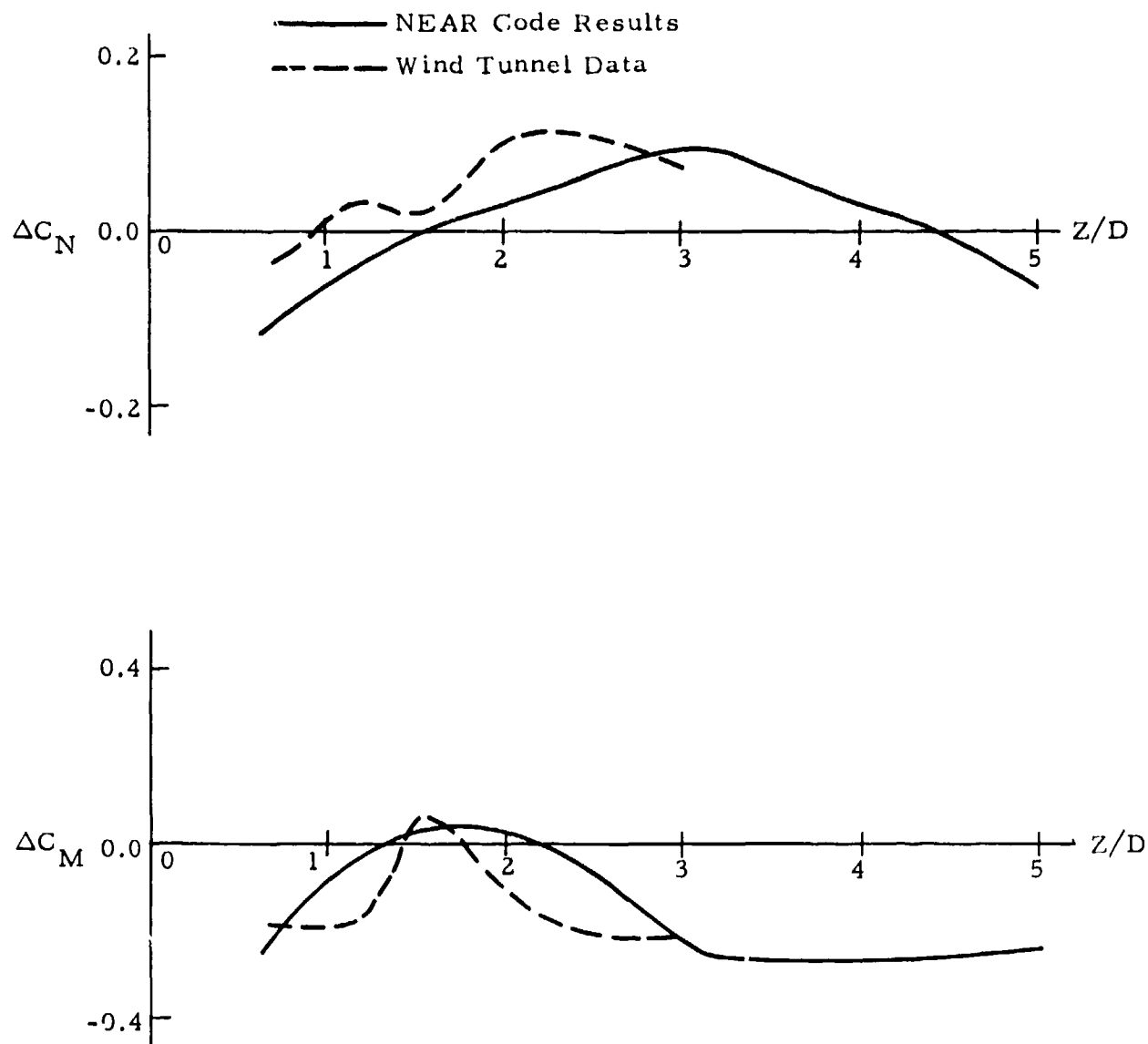


Figure 13. Comparison of Submissile Interference Aerodynamics as a Function of Submissile Vertical Displacement ($M = 1.2$, $X/D = 4.0$, $\alpha_D = 5$ deg, $\Delta\alpha_S = 0$ deg)

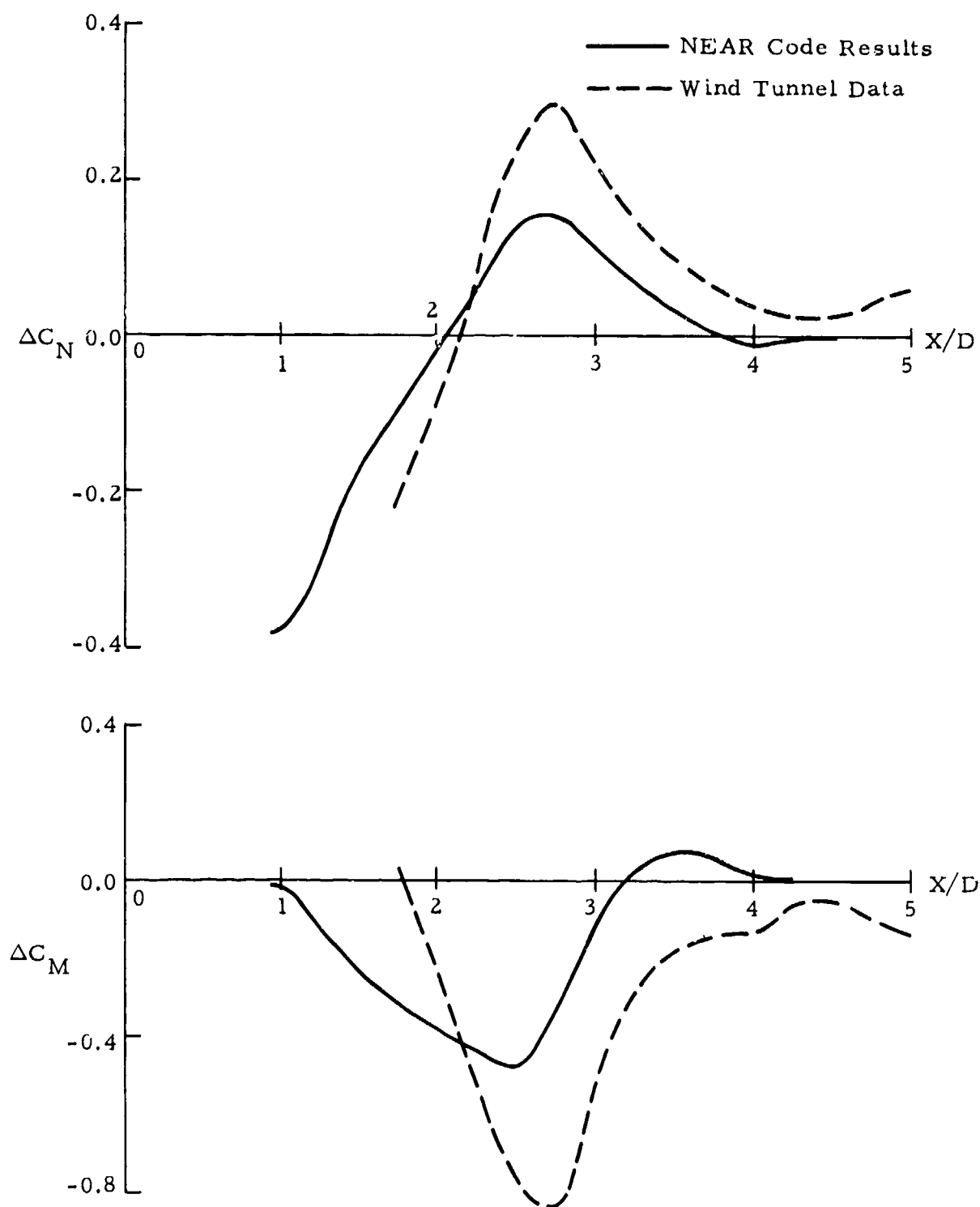


Figure 14. Comparison of Submissile Interference Aerodynamics as a Function of Submissile Longitudinal Displacement ($M = 1.2$, $Z/D = 1.0$, $\alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg)

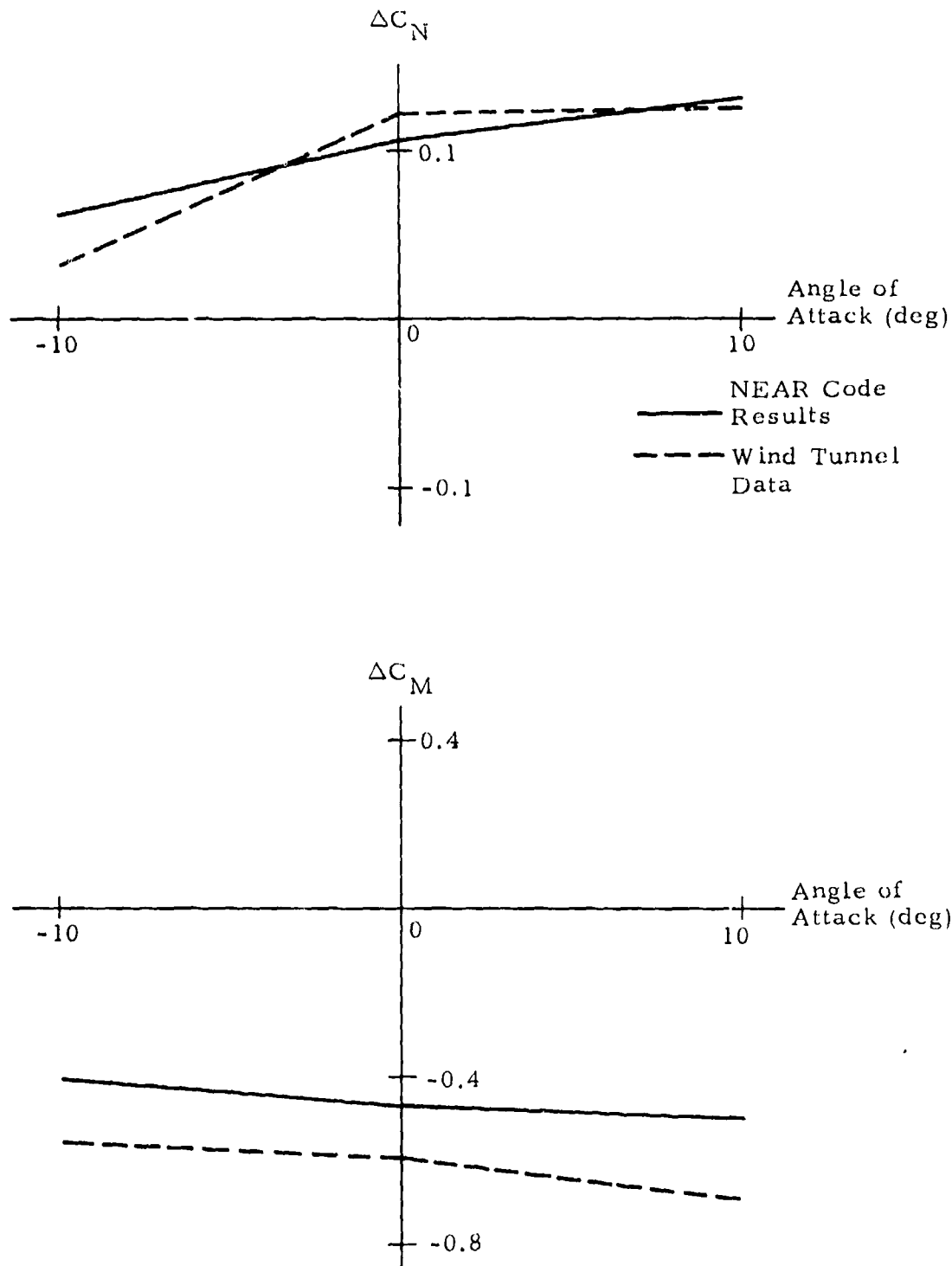


Figure 15. Comparison of Submissile Interference Aerodynamics as a Function of Submissile Angle of Attack Relative to Dispenser ($M = 1.2$, $X/D = 2.4$, $Z/D = 1.0$, $\alpha_D = 0$ deg)

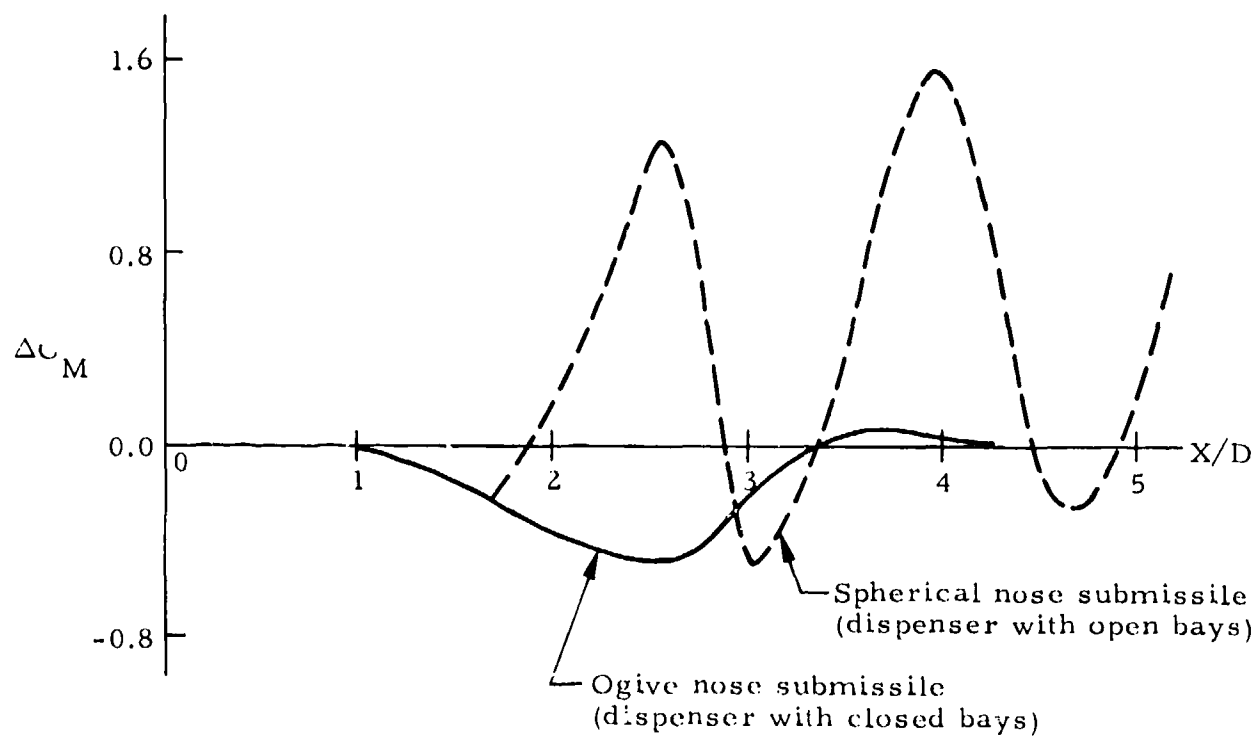
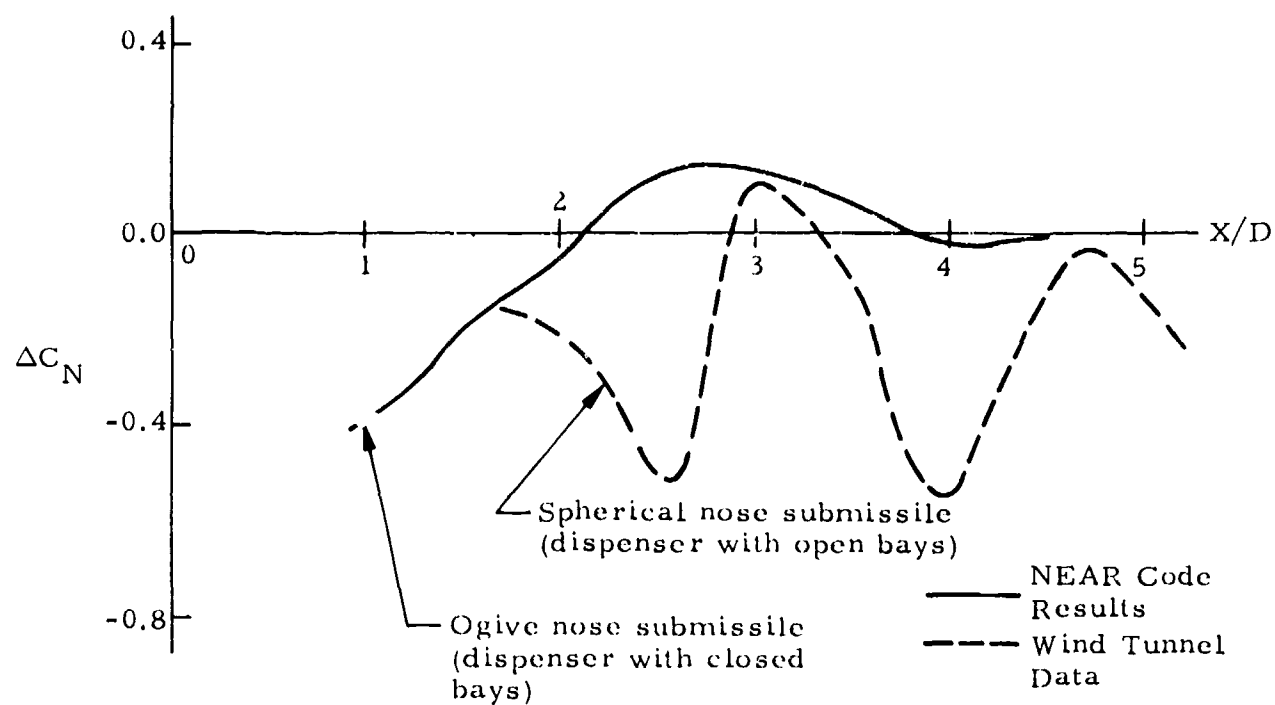


Figure 16. Comparison of Submissile Interference Aerodynamics
 Depicting NEAR Code Limitations ($M = 1.2$, $Z/D = 1$,
 $\alpha_D = 0$ deg, $\Delta\alpha_S = 0$ deg, Submissile with Fins)